# Getting ready for Petaflop & beyond

## A Utility perspective

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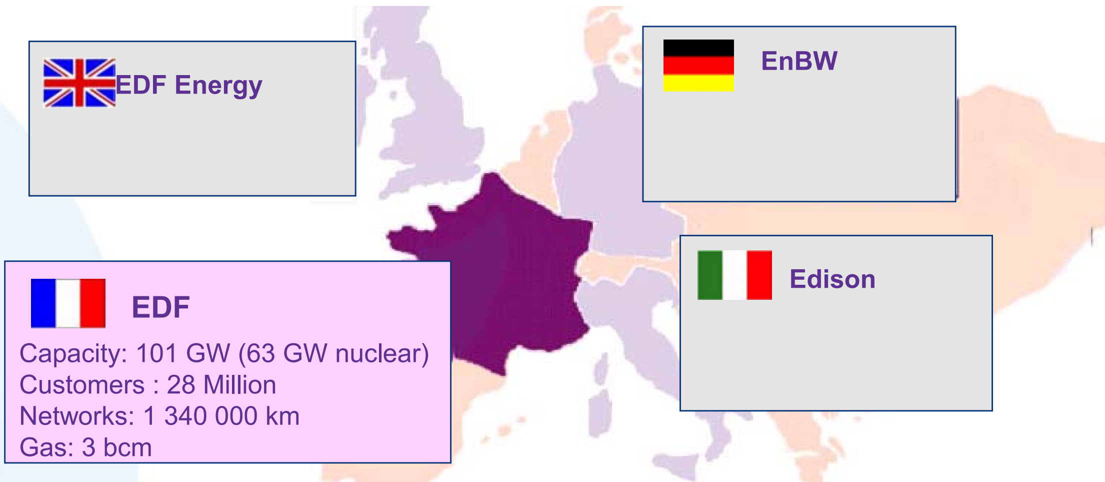
# Outline

- Why and how EDF got involved in HPC
  - EDF High Performance Simulation Challenge
- What we have achieved today and plan for tomorrow
  - Examples of first business benefits brought by HPC
  - R&D challenges ahead
- R&D priorities and partnerships
- Concluding remarks

# EDF key features



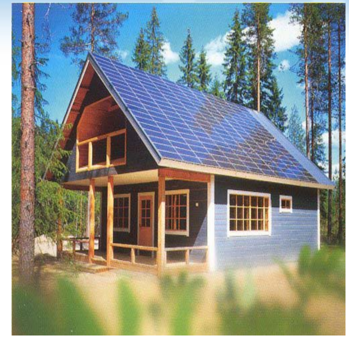

- 58 standardized nuclear units
- Industrial architect, responsible for nuclear safety
- Risk management through technical and scientific expertise: large engineering and R&D Divisions

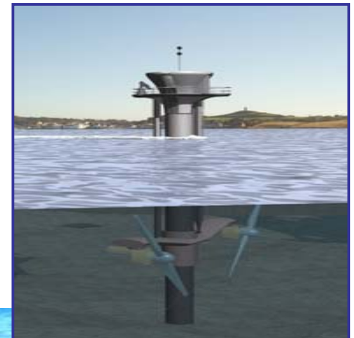
# Why HPC at EDF?

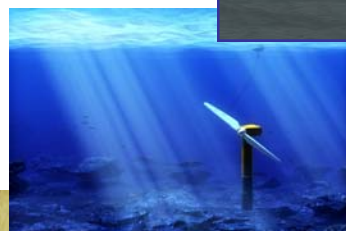
# Operating in a changing world

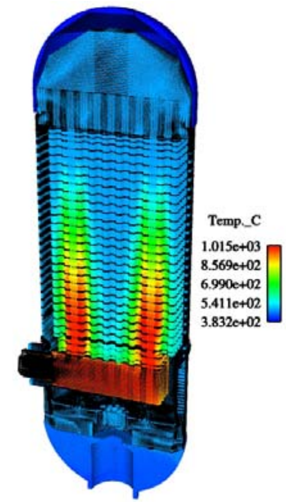
- Operation, maintenance and optimization of complex systems over 40 – 100 years:
  - guarantee safety, minimize environmental footprint
  - improve performances/costs
  - maintain assets
- Under changing operating conditions:
  - Market, regulations, environment
  - Ageing
  - Performance increase (technologies, operating modes,system optimizations)
- Push operationnal decisions closer to limits
  - Need for predictive simulation taking into account the complexity of real industrial environments

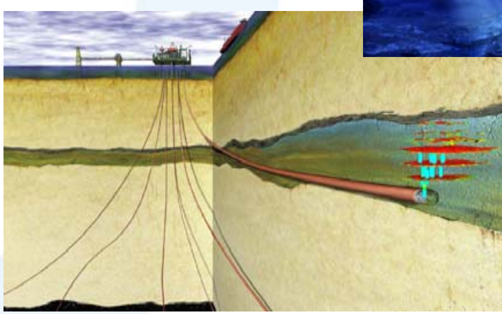
# New energy challenges

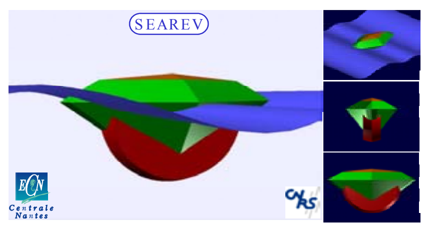






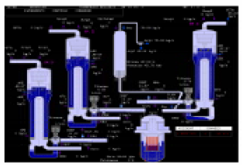


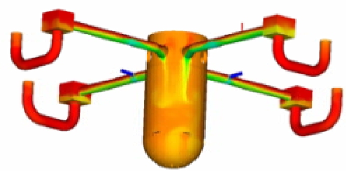



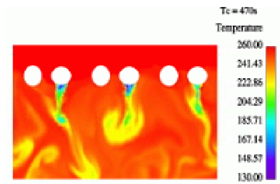


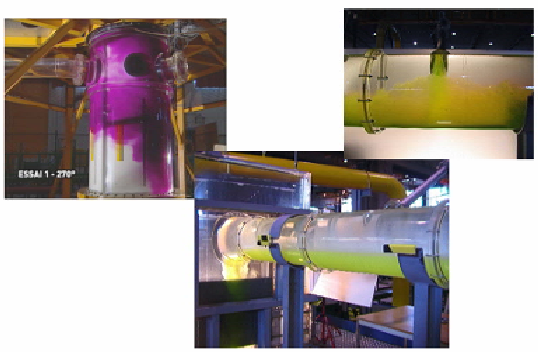
# Simulation promises …

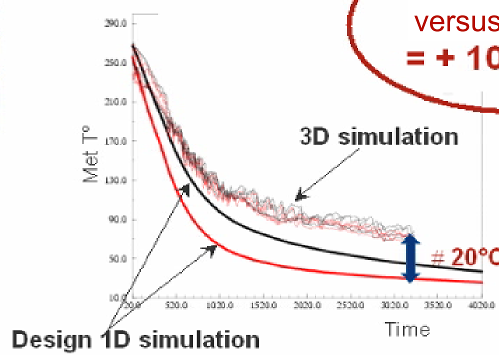
- More accurate simulation of hot and cold water mixing in the core vessel adds 10 years to life time margins.





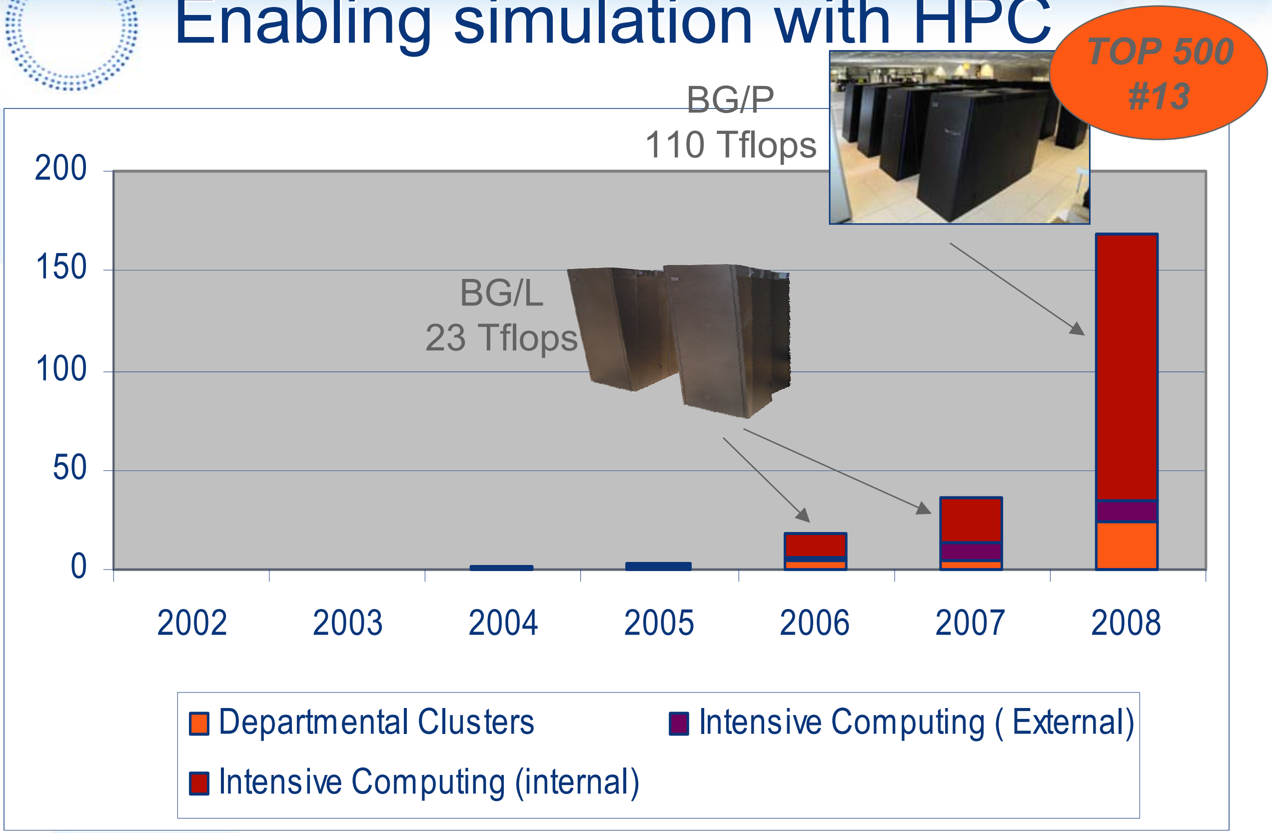



Simulation versus Design
**= + 10 years !**

# Enabling simulation with HPC



# BG configurations

**Blue Gene\L Configuration**

-4 racks, 4096 nodes, 8192 cores

-32 I/O nodes per rack

-1 Gbyte/s Ethernet  Cisco Switch

-2 System P Front-end nodes

-GPFS (45 TBytes, 4.5 GB/s sustained)

- 8 System P NSD Servers
- 6 DS4700 (SCSI Disks)

**Blue Gene\P Configuration**

-8 racks, 8192 SMP nodes, 32768 cores

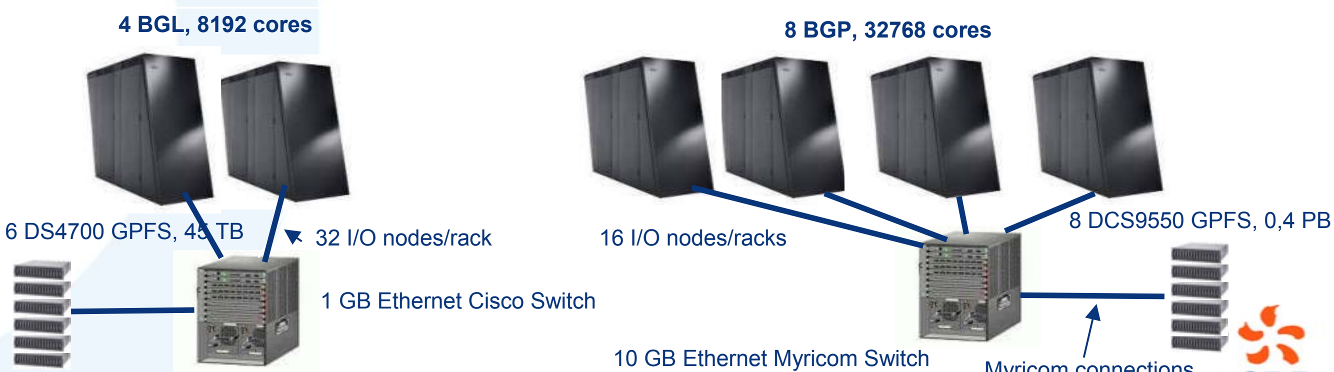
-16 I/O nodes per rack (I/O capacity and bandwidth will be doubled in 2009)

-10 Gbyte/s Ethernet Myricom Switch

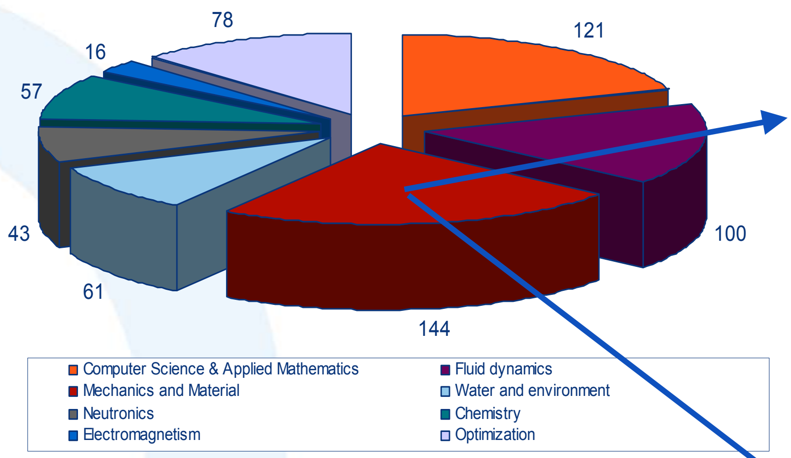
-2 System P Front-end nodes

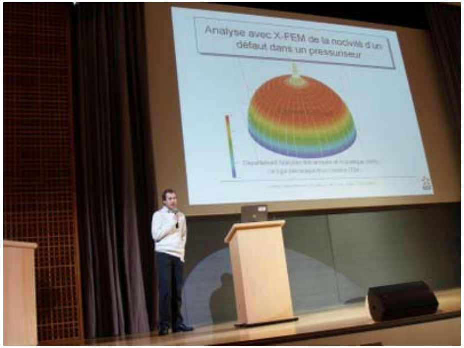
-GPFS (400 TBytes, 8 GB/s sustained)

- 16 System P x NSD Servers
- 4 DCS9550 (DDN technology)



# Building on simulation communities



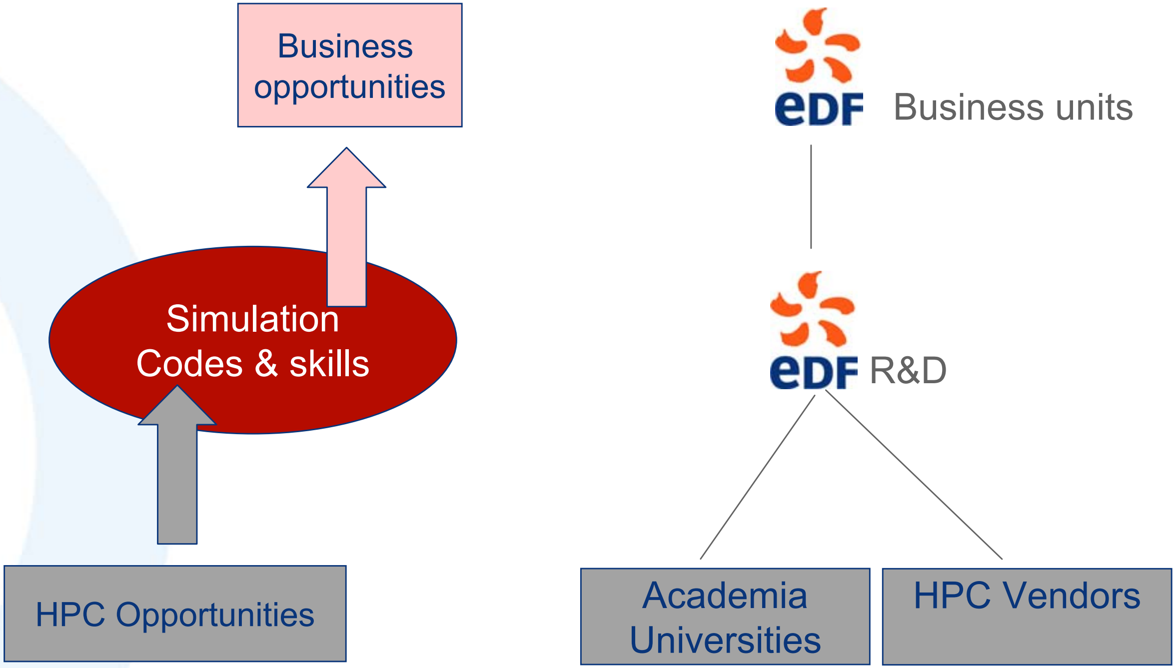



**600 simulation users, 150 developpers**

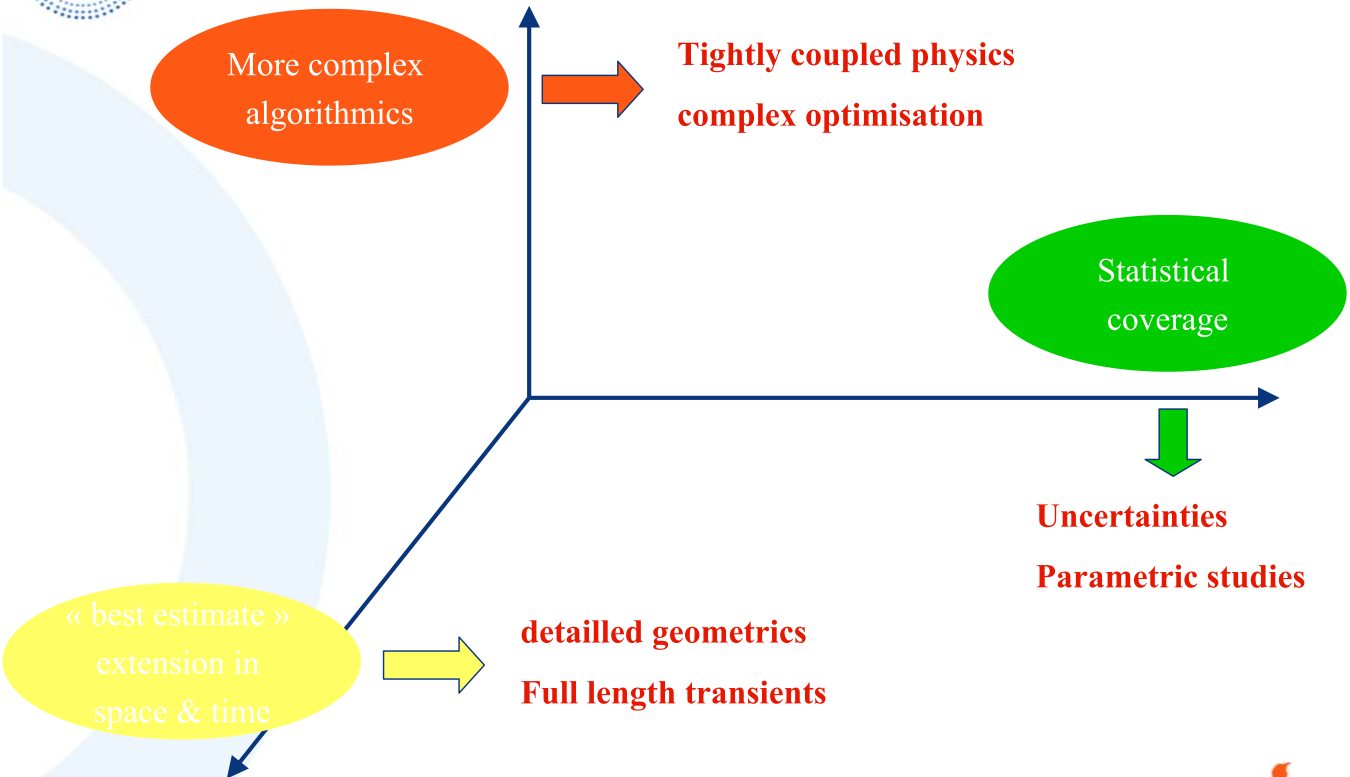
# Dealing with extensive simulation assets

| Name | ASTER | CYRANO | SATURNE/ SYRTHES | NEPTUNE | THYC | TELEMAC | TRIPOLI | COCCINELL E | CARMEL |
|---|---|---|---|---|---|---|---|---|---|
| Domain | Non-linear Structure thermo-mechanics | Fuel rod Thermo-mechanics | Mono-phasic fluid thermo-dynamics | Di-phasic fluid dynamics (CFD) | Di-Phasic fluid dynamics (porous media) | Free surface fluid dynamics | Stochastic neutronics (reference studies) | Diffusion neutronics (industrial studies) | Electro-magnetism |
| Owner | EDF | EDF | EDF | EDF/CEA | EDF | EDF | CEA | EDF | EDF/ LAMEL |
| Size (k lines) | 1500 | 150 | 450 | 120 | 100 | 190 | 250 | 200 | 20 |

# HPC/simulation Challenge



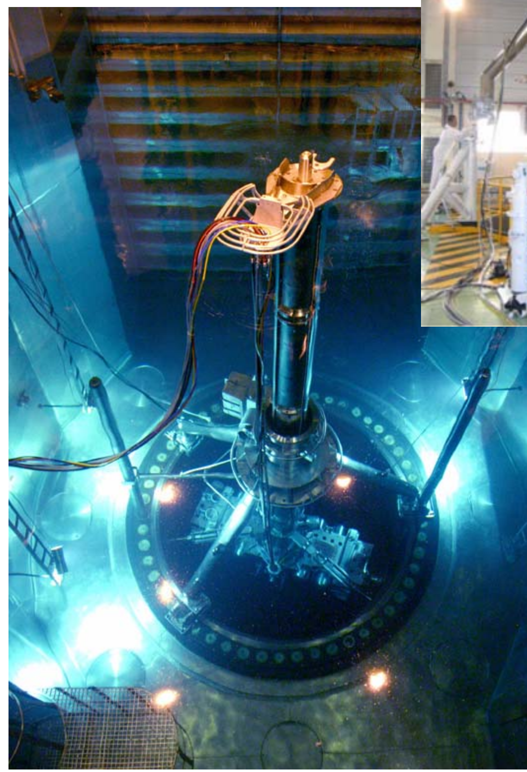
# HPC approaches



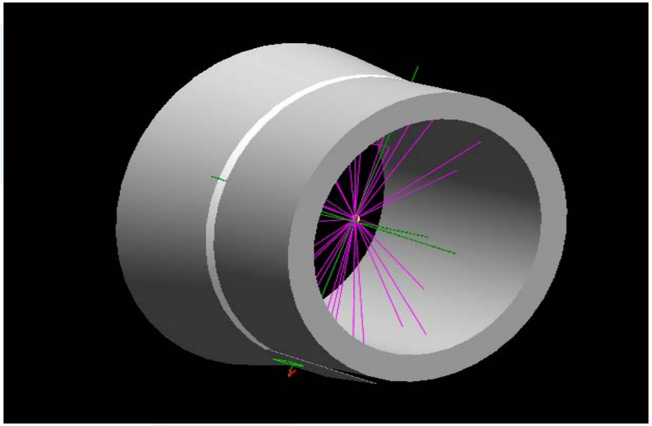
# First achievments & perspectives

# Non Destructive Examinations: NDE

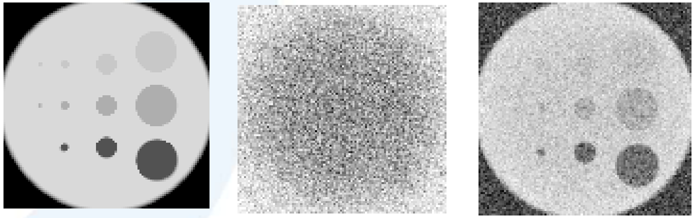
- Non-destructive tests are conducted during outages to monitor critical parts of nuclear plants, and detect potential defects; operations are costly and require fine tuning
- It is necessary to demonstrate that the particulars tests configurations will be efficient in the field
- This is usually done through physical tests on mock-ups
- High performance simulation can do that more quicky and more efficiently, at a lesser cost



# Application to radiographic NDE



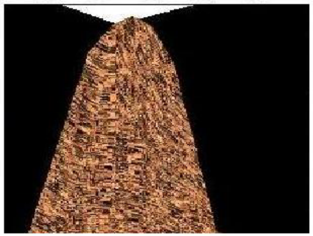
*Simulation of primary circuit piping*



*Simulation results on validation Test mock up*

- 100 mm thick steel primary circuit piping (defect is a few  mm long )
- Moderato code (Monte-Carlo), 150 billion photons: direct + scaterred  (1200 billion photons reference calculation)
- 1000 BG/L cores; 24 hours
- Parametric studies
  - Source  sensitivity (type and cone opening)
  - depth and orientation of potential defect
  - Distance from the part

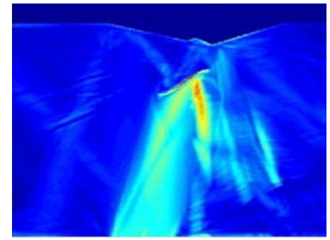
# Developments for ultrasonic NDE



weld under control

30 mm

simulation

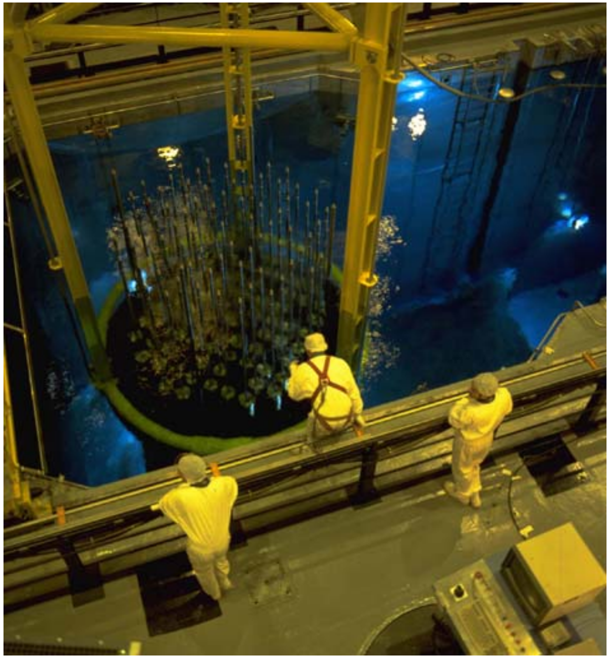


Maximum displacement

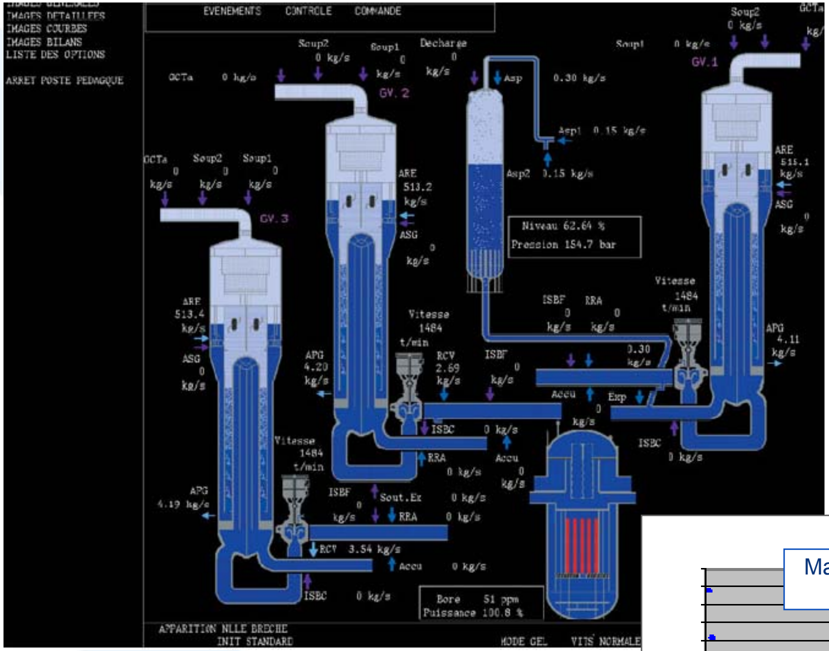
- Detectino of complex disoriented stress corrosion cracks in heterogeneous anisotopic parts; material grains generate « structure noise » on wave propagation
- Requests Finite Elements simulation of  US waves propagation (Athena 3D code) and advanced numerical methods: (Perfectly Matched Layers, fictitious domains, …)
- Problem size is 10 billion meshes (200 billion degrees of freedom), will need 20k+ cores (2 days wallclock time)
- Scaling work on Athena on-going with INRIA

# Nuclear fuel management studies

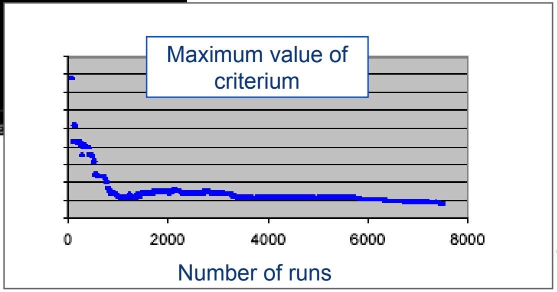
- Gaining flexibility in nuclear fuel loading patterns is a major performance improvement driver
- Changing practices from using “standardized reload assemblies” to more flexible reloads adapted to market needs requires :
  - A better assessment of margins during safety evaluations, for instance using probabilistic methods,
  - Safety evaluations covering a wide range of possible states of the nuclear core,.



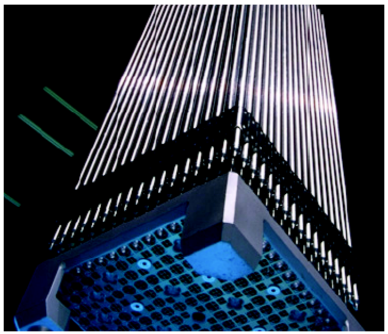
# Probabilistic LOCA studies



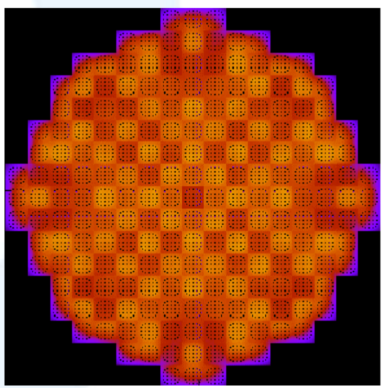

- test conducted on Cathare system code, stochastic laws for 74 out of 136 variables
- 8000 executions on 8000 BG/L cores (12 days wallclock time)
- 2,4% variance reduction demonstrated



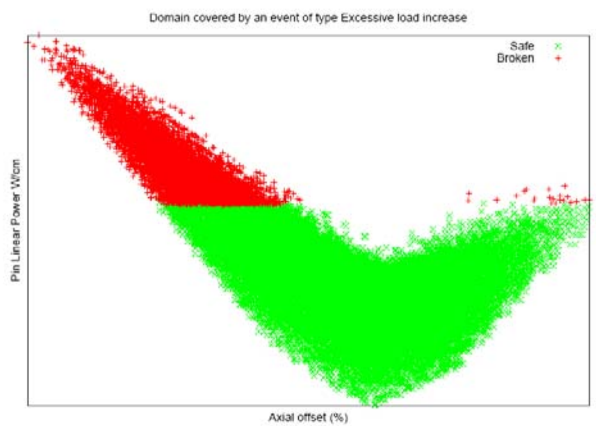
# Flexible reloading



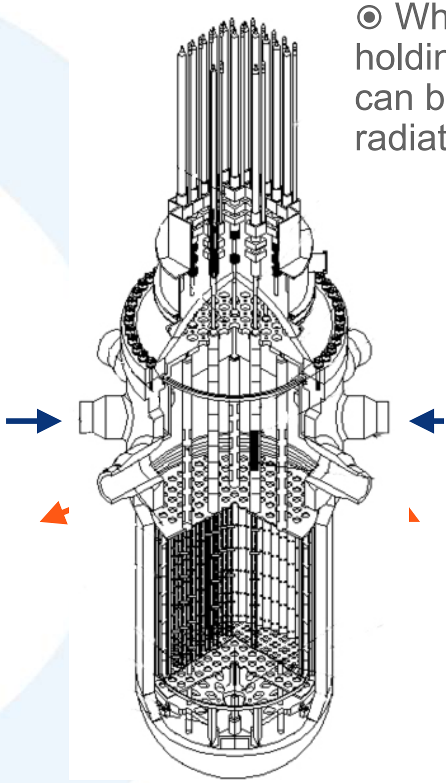
(b) Assemblage MOX



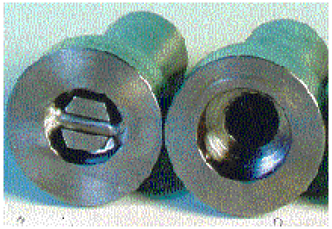
- Coccinelle reactor physics industrial code, static calculations over complete possible reactor states
- - > 4 burn-up levels,
  - > 10s xenon 3D distributions
  - 10 power levels
  - several 100s control rod positions, for each group of rods,
- Leading to : 200 000 * 1mn calculations. < 1hour wallclock time => > 10 k proc.

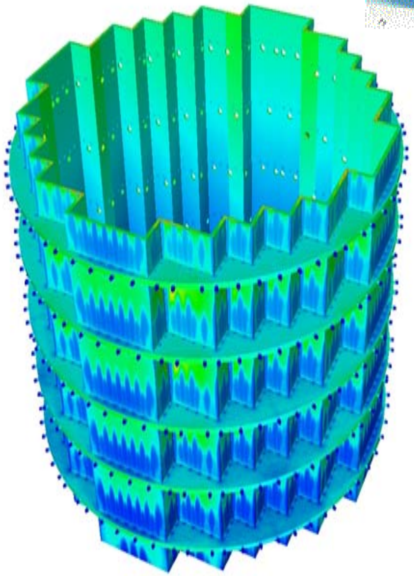


# Core maintenance

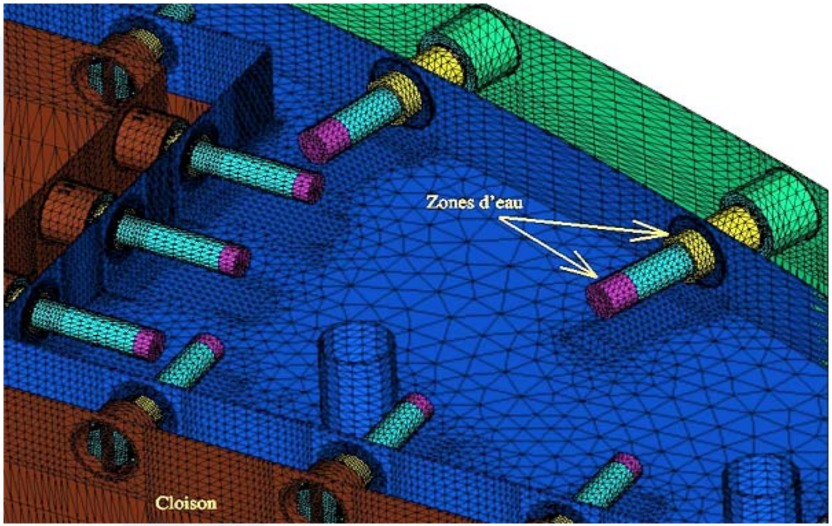


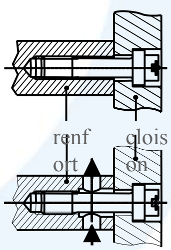
- Which bolts (among thousands holding the shuffle part in the core) can be affected by thermal and radiation degradation?

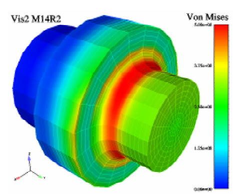




# Core maintenance

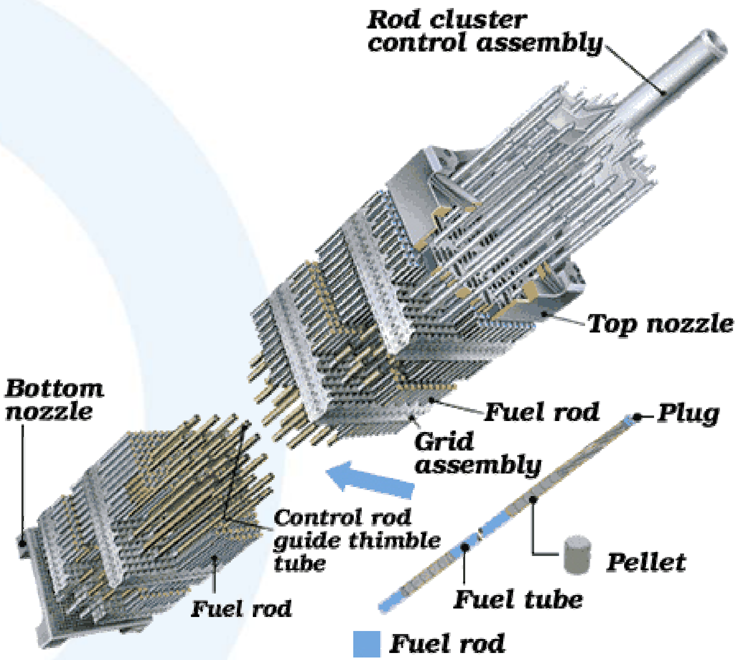



- A complex physical and geometrical problem
  - Calculating thermal and radiation impact on a large number of bolts holding the baffle within the core
  - multiphysics (neutronic, thermalhydraulic, mechanical aspects)
  - different scale between the global structure (4m high, 3.5m diameter), and the bolts (6cm long and less than 1mm for the fillet under the bolts head)
- Modelling of horizontal formers 2 to 6 on 360°
  - large meshing (1.1 billion elements) due to the large number of bolts
  - 1H30 calculation on BlueGene/L using 2048 processors

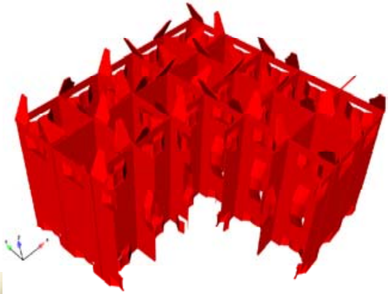
# Fuel assemblies mechanics

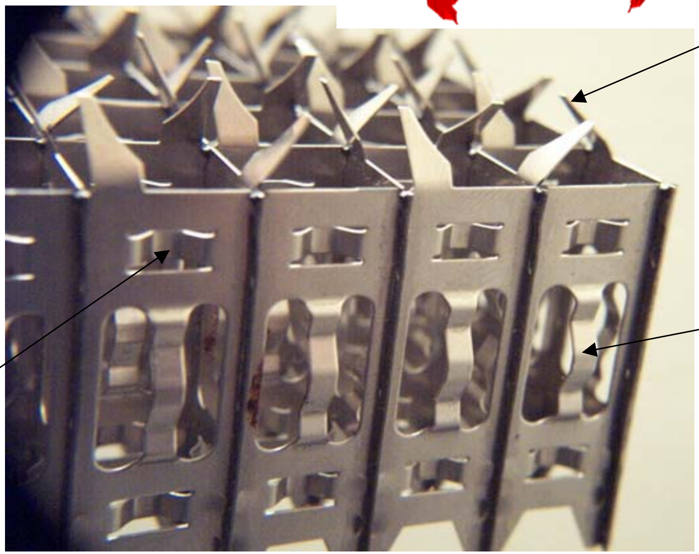



- Each 1300 MW Power plant contains 196 fuel assemblies
- Each assembly contains 17*17 fuel rods held together by 10 grids leading to very complex, non symetrical geometries
- Mechanical and vibratory behaviour of the fuel assemblies inside the core vessel is of major importance to operation
  - Assembly deformation
  - fretting

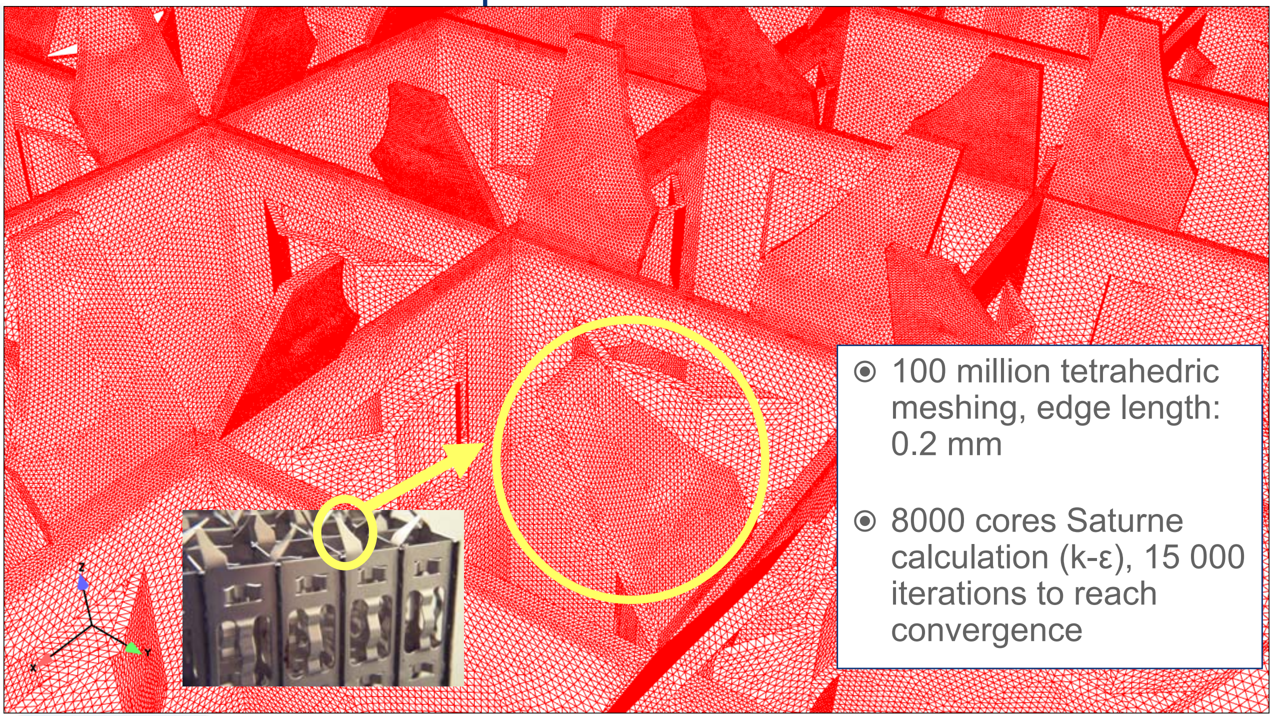
# Prototype calculation

- At each of the 10 grid levels, fuel rods are usually held in place by a spring/thimble combination
- Fuel rods must be able to slowly slide as they elongate due to irradiation, but must vibrate as little as possible to avoid wear
- “Mixing” grids have special “fins” in order to better homogeneize the flow
- First calculation was carried out on a prototype 5*5 grid

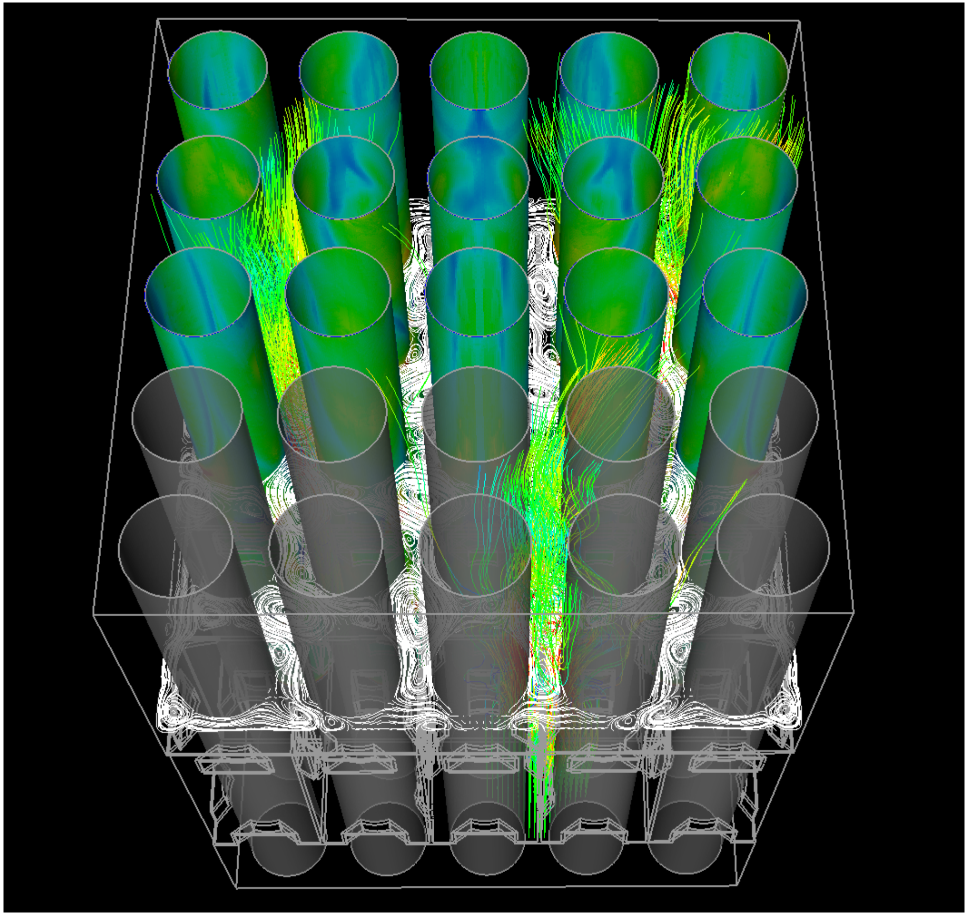




# Mixing grid meshing

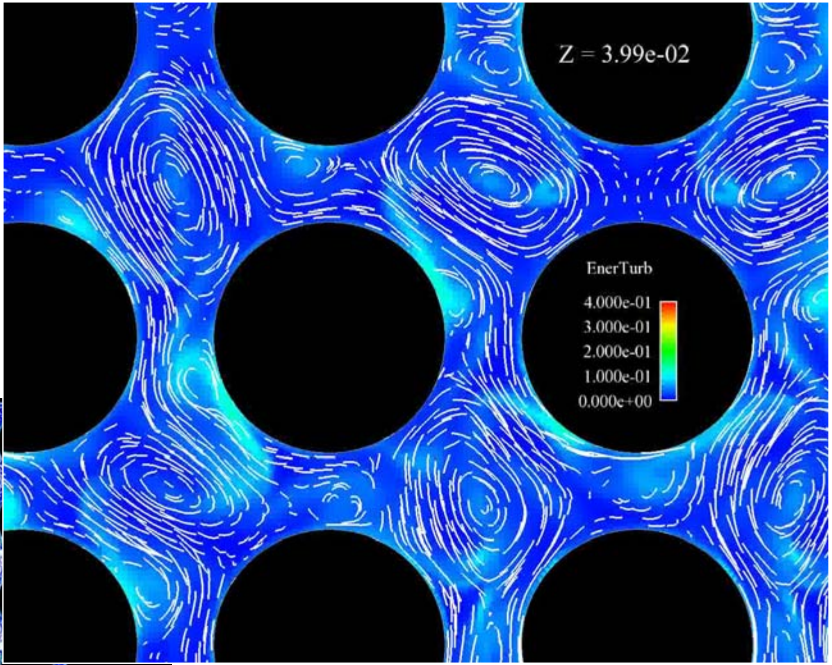


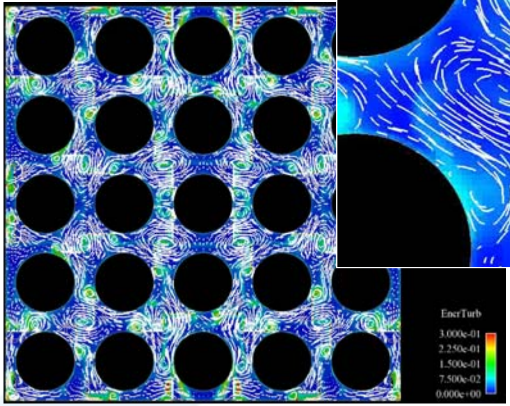
- 100 million tetrahedric meshing, edge length: 0.2 mm
- 8000 cores Saturne calculation (k-ε), 15 000 iterations to reach convergence



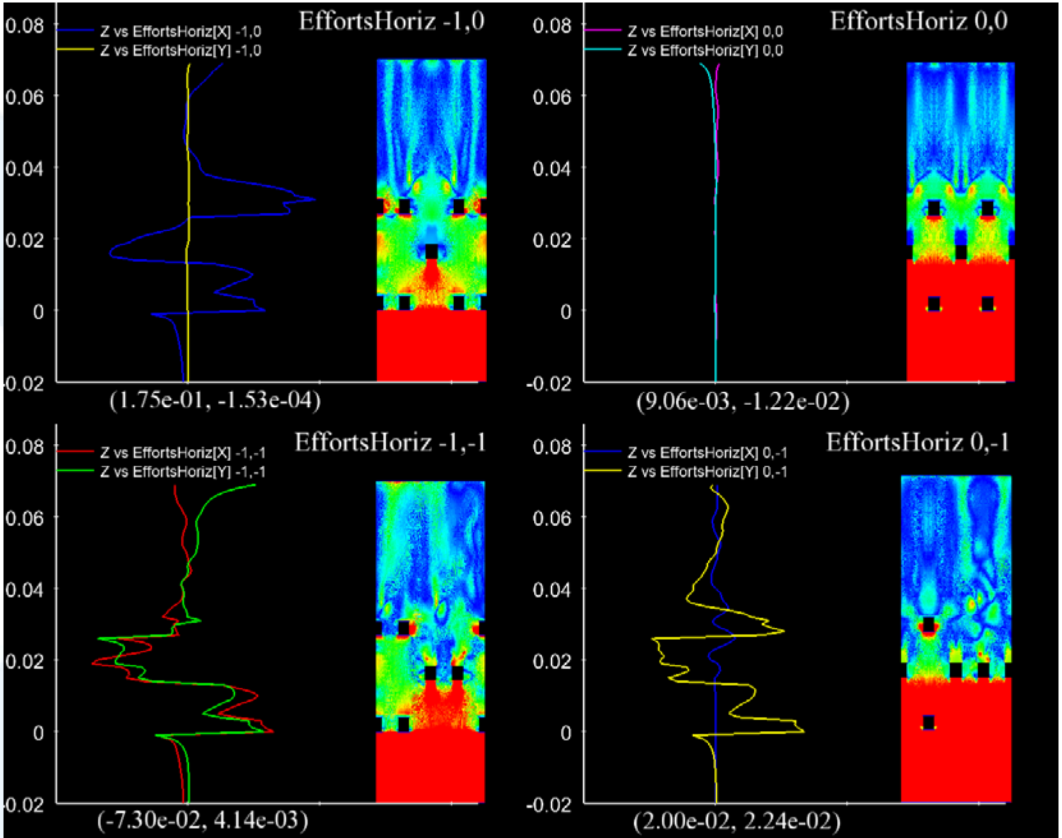
colored: vertical velocity streamlines
white: streamlines of the projected velocity on a horizontal plane

# Transversal flows



# Horizontal stress on rods

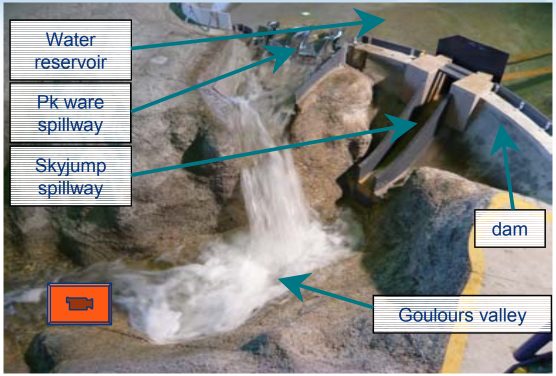


# Next steps

| 2007 | 2008 | Exaflop challenge? |
|---|---|---|
| 5*5 grid | 17*17 grid | Full core vessel :<br>• **17*17 grids**<br>• **10 grids per assembly**<br>• **196 assemblies** |
| K-ε | RANS-LES | RANS-LES |
| 100 millions tetrahedrons | 220 million hexahedrons | 300 billions hexahedrons |
| 1 converged solution<br><br>15000 iterations | Temporal analysis:<br><br>1s physical time<br>→ $2.10^5$ time-steps | Temporal analysis:<br><br>1s physical time<br>→ $2.10^5$ time-steps |
| Volumic data (full analysis): 4 Go<br><br>Skin data (rod interaction only): 75 Mo | Volumic data: 40 Go / step = 10 To<br><br>Skin data : 750 Mo / step = 15 Go | Volumic data: 60 To / step = 15 Po<br><br>Skin data : 1 To / step = 200 To |

# Spillways design

- following new climate change assumptions, dams have to accomodate more severe millenary floods (up to twice as severe water flows)
- Tens of dam spillways have to be redesigned
- Current practice uses physical mock-ups; studies can take up to 12 months
- HPC enables to tackle the problem through simulation
  - lagrangian code SPARTACUS (Smoth Particle Hydraulics)
  - 6 millions particles simulation have run on 8000 BG/Pcores, < 24 hours (1 minute wallclock time)
  - target: 20 million particles, 5 minutes wallclock time, parametric studies (weir geometry, spacing and length of piano keys, position of spillway)




*Mock-up*

*Construction*

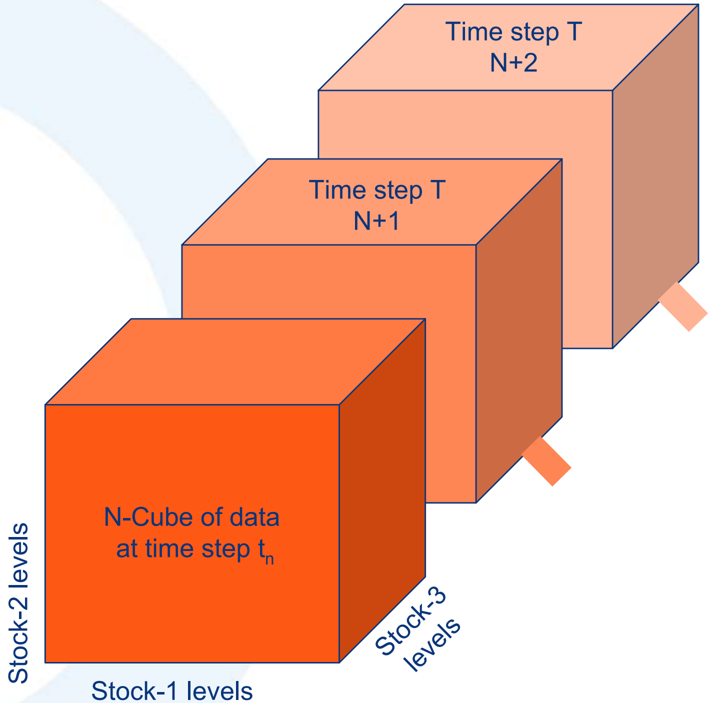
# Energy management





- How to best deliver the electricity requested by our customers ?
  - At minimum environmental impact
  - At minimum cost
  - At minimum risk
  - under uncertainty (demand load, availability of production, electricity & fuel market prices)
  - Every day! (hour, minute …)
- A huge optimization problem currently extremely simplified for lack of computing power

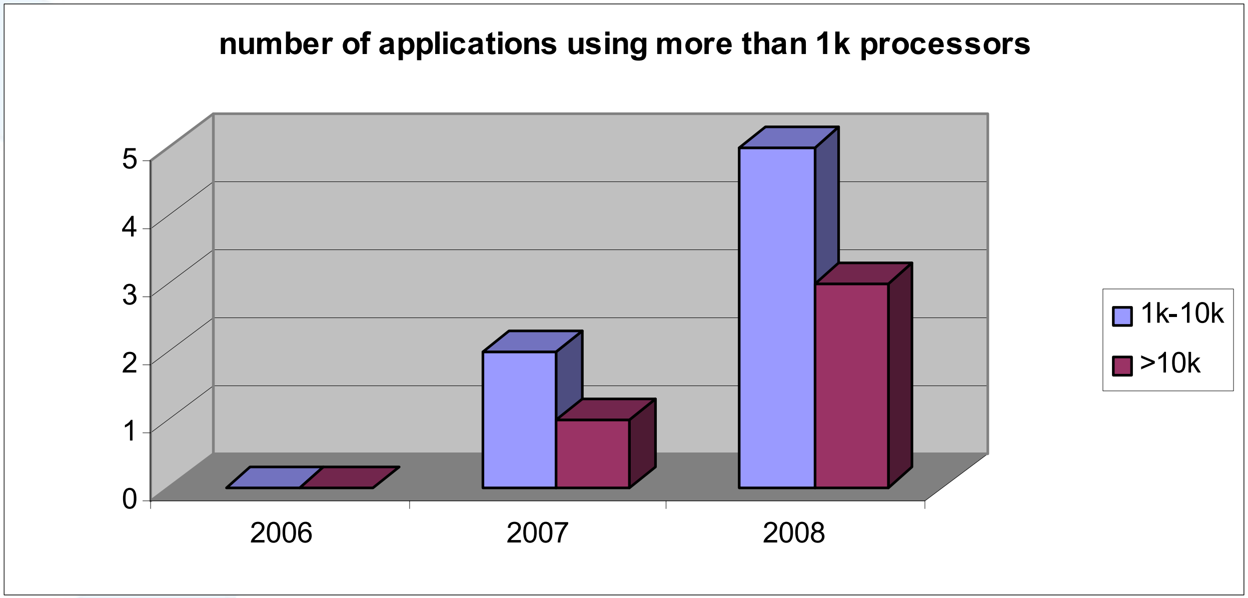
# Optimizing more energy stocks




- N-dimension stochastic dynamic programming
- Problem is exponential with number of stocks and constraints
  - water stocks, fuel stocks, demand-side options, market futures
  - Constraints: start-up, operating & shutdown ramps, dam dependancies in hydraulic valleys, SO2 emissions limits etc
- Current optimization limit of 4 stocks being upgraded to 10 stocks with 32000 BG/P cores computation
- Near infinite computation needs

# R&D
# priorities & partnerships

# Million core programming?



# Workshop in september

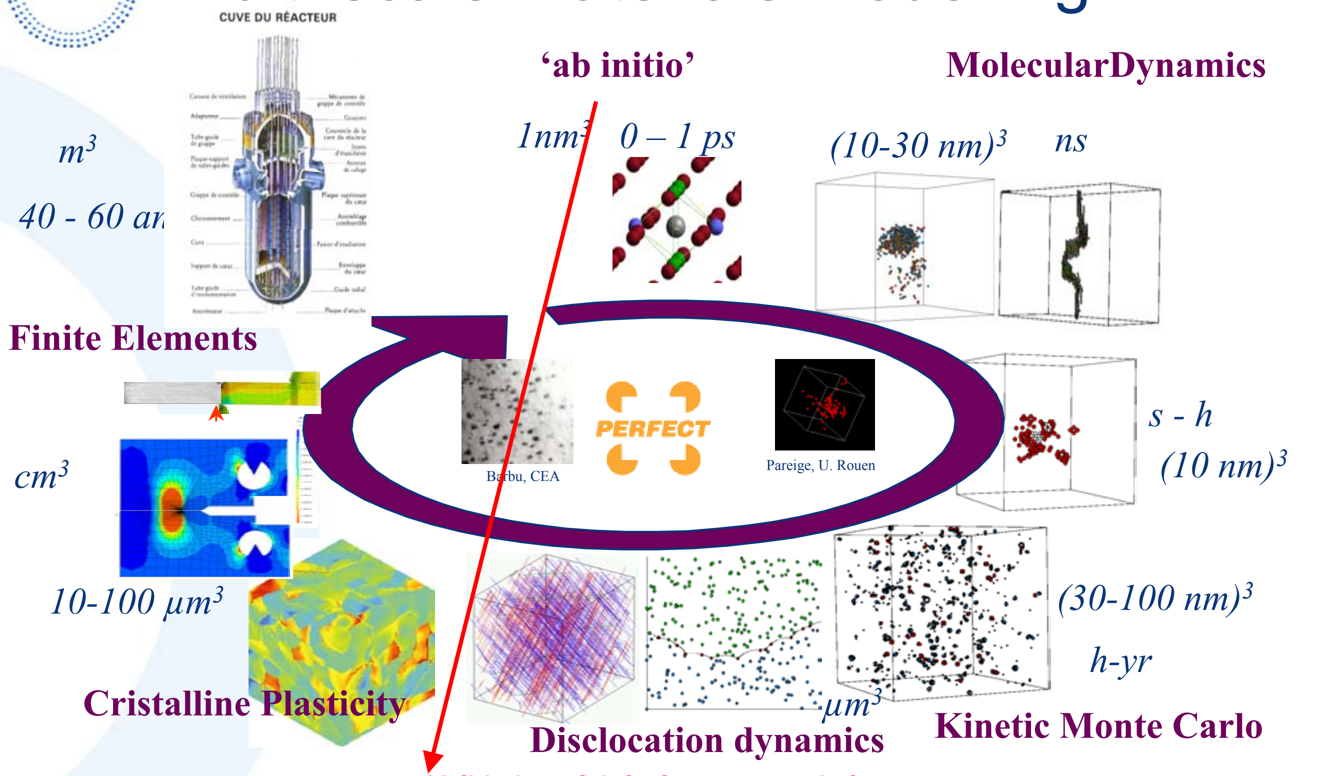
## Simulating the Future
## Using One Million Cores and Beyond

**Organization :**
**J. Dongarra, Univ. of Tennessee**
**JY Berthou EDF R&D**

# 23 M pixels visualisation

- 6*3 meter, 23 million pixels power wall
- 40 Gbit/s Alcatel Lucent optical network to HPC centers
- Start operation october 08

# Multi-scale materials modelling




Validation of default structures in Iron

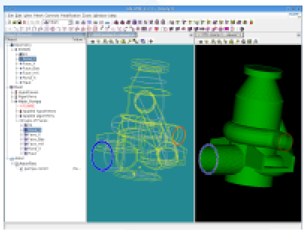
2007: 1000 calculations, 3nm cube, 1000 atoms, (1 calculation = 2 days, 500 processors)

# Materials Ageing Institute (MAI)

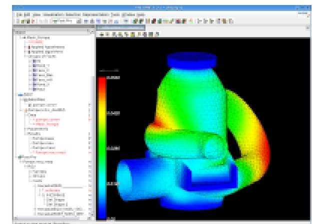
- An EDF-led initiative to leverage scientific and funding efforts on broad material issues between electricity utilities
- **Investigate, understand and simulate materials ageing mechanisms on the basis of operating experience feedback (1200 reactor-years) and lab results.**
- Disseminate knowledge through education & training : courses and lab work for students, training for utility staff, seminars and workshops
- Achieve a worldwide recognition, including by safety authorities
- Scope of activity :
  - Nuclear power plant issues (including GEN4), fossil fuel and hydropower facilities
  - Metallic, concrete, polymers
  - All degradation mechanisms (thermal ageing, irradiation assisted ageing, various types of corrosion, fatigue, creep, etc.) + cross-cutting issues (behavior of oxide layers, role of interfaces, etc)
- **Initial engagement by EDF, EPRI and TEPCO**
- Started January 2008, 10 projects (circa 8,8 M€)
- **Investment in new powerful equipment : SEM,TITAN TEM, Dual Beam Nanolab, Blue Gene super-computer**

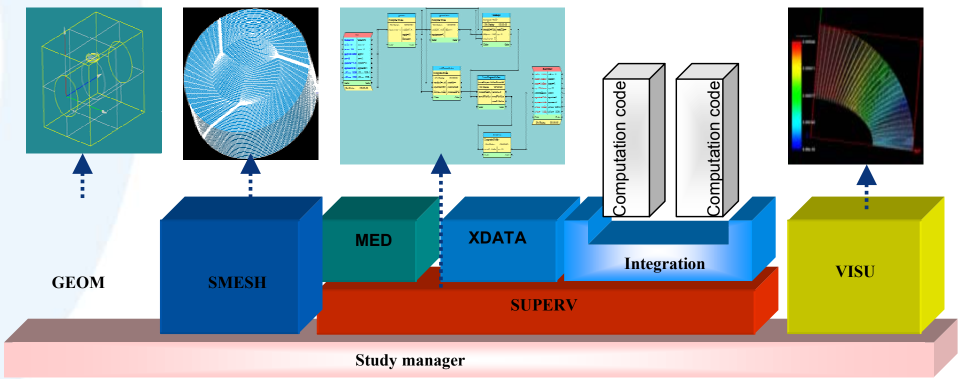
# Multi-physics/pre-post platform

- SALOME is a generic platform for pre & post processing and code, under GNU GPL licence, co-developped with CEA since 2001 in a consortium of 21 partners



http://www.salome-platform.org





# Salome consortium

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IRISA

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ECOLE DES MINES DE PARIS

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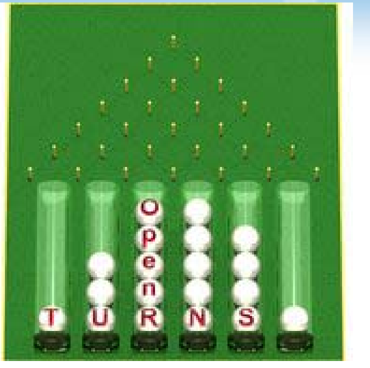
# Uncertainty platform




- OpenTURNS is an Open source initiative to Treat Uncertainties, Risks'N Statistics in a structured industrial approach.
- It has been developped since 2005 through a partnership between EDF, EADS and Phimeca
- Sources are under GNU LGPL, documentation and wiki content are under GNU FDL
- Target users:
  - Industrial pratitioners : access through GUI: Scientific C++ library  including an internal data model and algorithms dedicated to the treatment of uncertainties
  - Academic and research users: Python module with high level probabilistic and statistical operators

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# Concluding remarks

- Highest performance HPC is meaningful **ALSO** for an « end-user » like EDF
- We need a lot more than available today!
- Partnership with best players in computational science is a must.

From SciDAC to InDAC?


Thank you!